A VLT/UVES SPECTROSCOPIC ANALYSIS OF C-RICH FE-POOR STARS

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ABSTRACT

Large surveys of very metal-poor stars have revealed in recent years that a large fraction of these objects were carbon-rich, analogous to the more metal-rich CH-stars. The abundance peculiarities of CH-stars are commonly explained by mass-transfer from a more evolved companion. In an effort to better understand the origin and importance for Galactic evolution of Fe-poor, C-rich stars, we present abundances determined from high-resolution and high signal-to-noise spectra obtained with the UVES instrument attached to the ESO/VLT. Our analysis of carbon-enhanced objects includes both CH stars and more metal-poor objects, and we explore the link between the two classes. We also present preliminary results of our on-going radial velocity monitoring.

Key words: Stars: abundances, Stars: carbon, Stars: Population II, Stars: binaries: general

1. INTRODUCTION

A subgroup of carbon stars, the CH stars, were first distinguished from other carbon stars 60 years ago (Keenan 1942). Their chief characteristics are : strong CH absorption lines, strong Swan bands of C_2, strong resonance lines of Ba II and Sr II (later shown to reflect genuine overabundances of s-process elements), weak lines of the iron-group elements and high proper motion.

Since it was shown that all field CH stars were spectroscopic binaries (McClure & Woodworth 1990), the binary scenario was accepted: CH stars have been polluted by a nearby companion, formerly on the AGB, now a defunct white dwarf.

But some recent results have cast doubts on this general picture. Conflicting evidences include the radial velocity monitoring of targets from the HK survey (Beers et al. 1992) which show no radial velocity variations (Preston & Sneden 2001), and the discovery of carbon but not s-process enhanced stars (e.g. Sneden et al. 1996) . Furthermore, the unexpectedly high fraction of carbon-enhanced stars among metal-poor stars discovered in the HK survey (about 25% in the metallicity range [Fe/H] $\leq$ -2.5 compared to 1-2 % among stars of higher metal abundances), make them crucial for the study of the early stages of Galaxy evolution.

Table 1. The sample and the atmospheric parameters.

star	T_{eff}	log g	[Fe/H]	$^{12}C/^{13}C$
CS 22891-171	5100	1.8	-2.31	5
CS 22942-019	5100	2.5	-2.48	7
CS 22945-017*	6400	4.3	-2.60	4
CS 22953-003	4600	1.0	-3.27	>5
CS 22956-028*	6700	3.5	-2.38	3
CS 30322-023	4000	0.0	-3.78	5
HD 26*	5200	2.6	-0.71	?
HD 5424*	5000	3.0	-0.41	4
HD 24035*	5000	3.7	0.16	4
HD 168214	5200	3.5	-0.03	?
HD 187861*	4800	1.8	-2.21	10
HD 196944*	5250	1.7	-2.21	?
HD 206983	4550	1.6	-0.93	4
HD 207585*	5800	4.0	-0.35	10
HD 211173	4800	2.5	-0.17	13
HD 218875	4600	1.5	-0.63	100
HD 219116	4800	1.8	-0.45	7
HD 224959*	5000	2.0	-2.08	7
HE 1419-1324	4900	1.8	-3.28	4
HE 1410+0213*	4550	1.0	-2.38	4
HE 1001-0243*	5000	2.3	-3.12	30

* probably binary, from radial velocity monitoring

2. OBSERVATIONS AND ABUNDANCE DETERMINATIONS

We have started a new extensive high-resolution analysis of carbon-enhanced stars, based on a sample including at the moment 86 stars, aimed at investigating the C-enrichment phenomenon over a wide range of metallicities, chosen in the Barktevicius catalog (1996), in the HK survey and in the Hamburg/ESO survey (Christlieb et al. 2001). Observations were made with the VLT/UVES echelle spectrograph at high S/N and spectral resolution, as well as with the ESO 1m52/FEROS spectrograph. A few radial velocity observations were made with the OHP 1m93 ELODIE instrument.

In Table 1, we present a subset of our sample for which we have derived C, N (from CN and CH bands), O (from [O I] 630nm, when possible), and Ba and Eu abundances, from VLT observations.

Effective temperatures were initially estimated from photometry available in the literature, using the calibra-
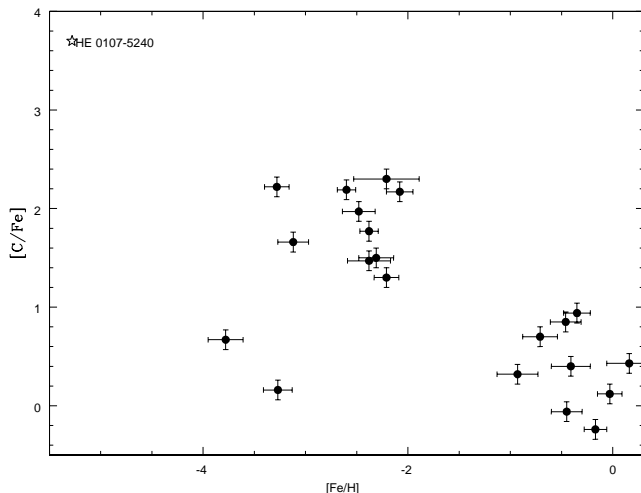
Figure 1. Carbon abundance vs. iron abundance. Despite some scatter, an increase of the carbon overabundance with decreasing Fe/H is clearly visible. Note that the most Fe-poor star HE 0107-5240 (Christlieb et al. 2002) follows the trend.
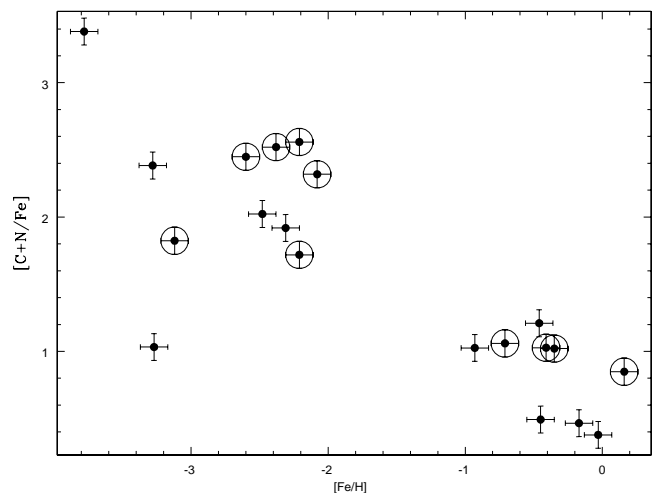

Figure 2. Carbon plus nitrogen abundance vs. iron abundance. For the majority of the stars, the global enrichment in (C+N)/H is approximately independent of Fe/H, indicating a primary origin of C (and N, possibly through posterior CN-processing). Suspected binaries, detected through radial velocity variations, are circled.

tion of Alonso et al. (1999). However, due to strong absorption by molecular CH and CN bands impacting the photometry by an unknown amount, T_{eff} were instead derived by forcing the abundance determined from individual Fe I lines to show no dependence on excitation potential. The gravity was determined from the ionization equilibrium of Fe I and Fe II. The microturbulent velocity was set by requiring no trend of Fe I abundance with equivalent width. The observed spectra are compared to synthetic ones, computed with the "turbospectrum" package (Alvarez & Plez 1998). This program uses OSMARCS atmosphere models, initially developed by Gustafsson et al. (1975) and later improved by Plez et al. (1992); see Gustafsson et al. (2003) for details on recent improvements.

The line lists are the same as used by Hill et al. (2002) for atoms and for CH, C_2 and CN, and their various isotopes.

3. RESULTS

Figures 1, 2, 3, and 4 present the derived abundances. Carbon is indeed enhanced in the atmospheres of most of our metal-poor targets (Fig. 1). Excluding the 2 stars around [Fe/H] = −3.5 that do not show a large C enhancement, the average carbon abundance is almost constant from the CH stars ([Fe/H] > −2.0) to the very metal-poor carbon-enhanced stars (from [C/H]≈ 0 at solar Fe/H to [C/H]≈ −0.5 at [Fe/H]≈ −3). The lowest metallicity star HE 0107-5240 ([Fe/H] = −5.3, recently discovered by Christlieb et al. 2002), shows a carbon abundance close to the solar value. This extreme star follows the trend

of Fig. 1. The nitrogen abundance, when combined to the carbon abundance and the carbon isotopic ratio, provides additional information. Figure 2 shows the sum of C and N overabundance as a function of Fe/H. Some of the stars that did not show a large C/Fe do show a large (C+N)/Fe, as the most metal-poor star of our sample. The $^{12}C/^{13}C$ ratio is generally low (see Table 1), often close to the CN-cycle equilibrium value. There is a general anticorrelation between the N overabundance and $^{12}C/^{13}C$ (Fig. 3), characteristic of the operation of the CN cycle. Note that the stars of our sample with low $^{12}C/^{13}C$ and still on the main sequence (cf. log g values in Table 1) are binaries, supporting the mass-transfer scenario. The carbon and nitrogen enhancements are large, and whether the CN cycling happened in the stars we observe when they evolved to the giant stage, or in the companions that polluted them, remains to be determined. The combined (C+N)/Fe overabundance is much larger at lower metallicity, pointing towards a primary origin of these elements. Asplund (2003) warns for 3D effects that may lead to overestimates of abundances derived from molecular lines in metal-poor stars, but we doubt that the trend could be erased by NLTE and 3D effects.

Ba is an s-process element and, as for carbon, its overabundance is explained by mass-transfer from a now extinct AGB star. The r-process element Eu is believed to originate from supernovae, although the r-process site(s) is still debated. Figure 4 shows [Eu/Fe] vs. [Ba/Fe] for the stars of Table 1. In addition to a few stars that are very
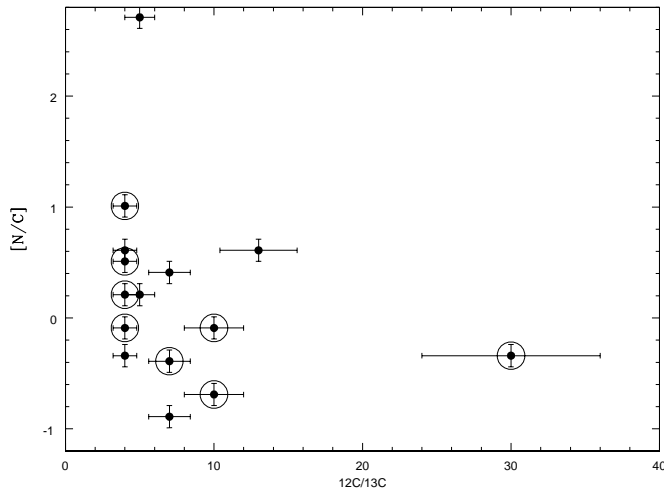
Figure 3. Nitrogen enrichment vs. $^{12}C/^{13}C$ ratio, showing the operation of the CN-cycle. Suspected binaries are circled.
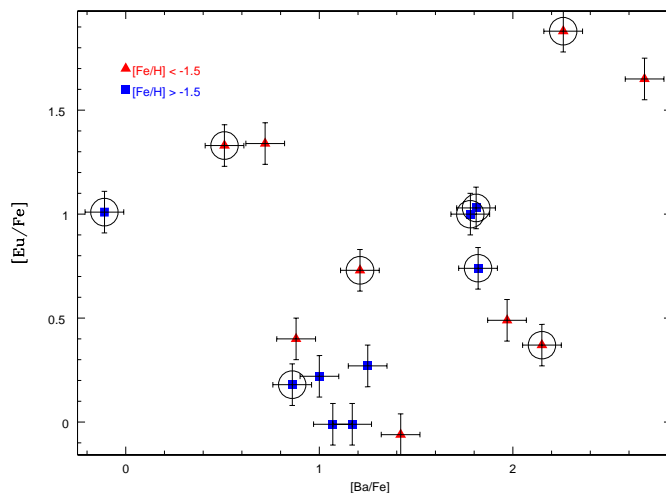

Figure 4. Eu vs. Ba abundances. The various origin of carbon-rich, Fe-poor stars is obvious in this diagram, where stars enriched in r-process elements, or in s-process, or maybe both, seem to exist at various metallicities. Suspected binaries are circled.

enriched in both r- and s-process elements, two groups emerge: one enriched in Eu and not in Ba, and a large group of stars with [Ba/Fe] around +1, and no or little Eu enhancement. This latter group encompasses the solar metallicity Ba stars present in our sample.

The carbon-rich, very iron-poor stars are of various origins: (i) mass-transfer binaries polluted by an AGB or a more massive star, (ii) single stars, some enriched in s-process elements, other in r-process elements, some maybe in both. We are pursuing our analysis of more stars in our sample, and of more chemical elements, in order to provide useful constraints on their origin, and on the early chemical evolution of the Galaxy.

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